REVIEW: VSC BASED HVDC TRANSMISSION LINE

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ABSTRACT

Rapid development in the field of power electronic devices with turn-off capability, like Gate Turn-off Thyristor (GTO) and Insulated Gate Bipolar Transistor (IGBT), makes the Voltage Source Converter (VSC) getting more and more attractive for High Voltage Direct Current Transmission (HVDC) [1]. This technology is called VSC-HVDC. It provides substantial technical and economic advantages for different applications compared to conventional HVDC transmission systems based on thyristor technology.

This paper review different technology presented by authors in past for future researcher study and research. From control point of view VSC HVDC provides greater flexibility in high power application then classical HVDC.

Keyword: - *VSC, HVDC.*

1. INTRODUCTION OF VSC BASED HVDC

Current source converter are thyristor based line commuted converters. These converters are called as classical HVDC. Development of high frequency fully controlled switches like IGBT and DSPs for generation of appropriate switching pattern provides a platform for efficient control of power flow through VSC [1]-[4].

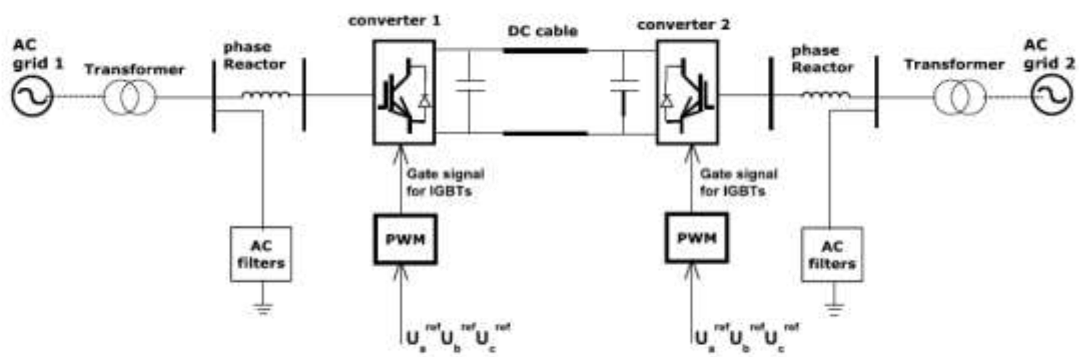

Fig.1:- A Back to Back VSC- HVDC transmission.

From control point of view VSC HVDC provides greater flexibility in high power application then classical HVDC. Advantages of VSC over CSCs are

- It provides an independent control of real and reactive power exchange between VSC with AC grid. No extra reactive power compensation is required.
- No risk of commutation failure occurs due to disturbances in power system.
- It can generate a balanced 3-ph voltage as synchronous generators, hence is useful for black start.
- It won’t have any reactive power demand like line commutated converters. It can control reactive power at converter stations to have desired AC voltage waveform.

The above advantages demands VSC for certain applications.

- Dynamic voltage control and black start capability of VSC enables for supply from remote location without any local generation [2], [13].
- Control of reactive power and AC voltage provides an improvement in a reliable power transfer and grid stability [1].

VSC-HVDC based HVDC transmission consists of an AC filter, transformer, phase reactor, DC link capacitor and voltage source converter as shown in Figure 1.

1.1. AC side filters

Filters are required to filter out undesirable harmonics. Harmonics in AC system causes overheating, losses, interference in communication line, malfunctioning of operation, over voltage due to resonance and instability in control system. Filters involved in VSC is cheaper as compared to classical HVDC as PWM technique reduces the harmonic content to a great extent. It acts as a high pass filter, and connected between transformer and converter which restrict the harmonics to enter in to AC system. We are getting fundamental frequency voltage and current at secondary side [11].

1.2. Phase reactors

It has advantage like preventing high frequency harmonics in AC line current as it act as like a low pass filter. Restricts the change in current direction through the IGBT switches. it provides a decoupled control of real and reactive power by controlling the current through it and it limits short circuit current. It is usually between 0.1 to 0.3 pu [11].

1.3. Transformer

It is helpful for keeping the secondary voltage level as per converter requirement. Reactance of transformer decrease the short circuit current level. It act as like a barrier between AC and DC side. A two winding transformer can be used for VSC converter. It is not needed to block the DC component.

1.4. Converter configuration

Voltage source converters are connected in back to back fashion where one act as like a rectifier and other one act as like an inverter. Converter that is used may be a 2 level, 3 level or multilevel converters. For 2 level VSC it is needed to have a six pulse generator for triggering six switches each switch consists of an IGBT and an anti-parallel diode and it generates two voltage level at AC side i.e 1/2 Vdc and – 1/2 Vdc [4].

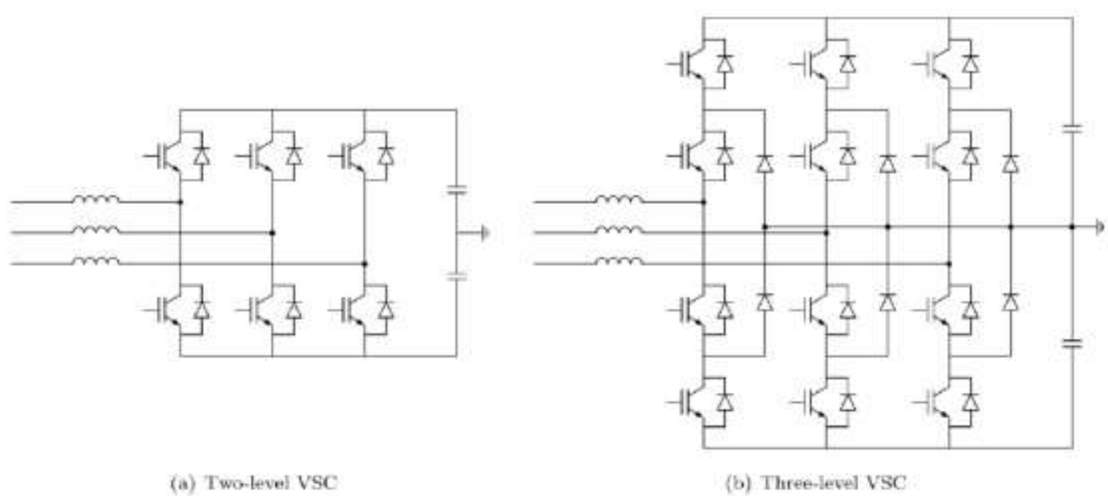

Fig.2:- 6 pulse and 12 pulse power electronics switch based HVDC converter.

For three level converters there are 12 switches and twelve pulse generator is required for triggering IGBTs. Three are three level of voltages at AC side of converter i.e ½ Vd , 0 and – ½ Vdc. And a comparatively low harmonic content is realized in three level converters [4].

1.5. DC link capacitor

DC link capacitor used in VSC transmission system act as a constant voltage source. It won't allow the change of polarity of DC bus. It is helpful for maintaining DC link voltage close to its desired level. DC link capacitor decides the transient response of the system. Hence deciding the value of the DC link capacitor is a challenging task. As the current with harmonics generated from PWM switching of IGBTs, flowing to capacitor creates a voltage ripple at DC side. Size of capacitor can't be determined from steady state operation as it leads to DC over voltage. It is important to consider the transient over voltage constraint when choosing the DC capacitor value [11].

Time constant τ determines the time required to charge the Dc capacitor from zero to its DC voltage level at nominal apparent power of the converter is

$$\tau = \frac{1}{2} C \frac{Vdc^2}{S_n}$$

Where Udc is the DC link voltage and Sn is the nominal apparent power. τ is the time constant to charge the capacitor from zero to its maximum DC voltage level [4], [11], [12].

1.6. DC cable

Extruded polymeric insulations are used particularly to provide resistant to the DC voltage, hence it is used in VSC-HVDC application. Whereas AC XLPE cables are not directly used for HVDC application due to a phenomenon called space charges. Electric field created by the DC voltage cause the space charge to move and concentrate at a certain spot of the insulation, resulting in degradation. Special XLPE cables are developed to avoid problem caused due to space charge. A rapid change in polarity change causes a high stress in insulation. As in VSC-HVDC polarity reversal is not required, XLPE cables can be used. Cables with ± 320 kv DC are presently available [11].

2. DIFFERENT TECHNOLOGY FOR VSC-HVDC SYSTEM

A function based fuzzy control system [13] is proposed for the control of active power, DC voltage at converter station and voltage at inverter station. Basically two input one output methodology based fuzzy logic controller has been proposed. The basic features of proposed system used in VSC based HVDC systems are: 1) only two rule base system is used 2) all controllers are not self-correcting. At both stations error and change in error have been taken as input to the controller. Design of high pass filter with FFT analysis has also been proposed for a better dynamic performance of the function based fuzzy controller.

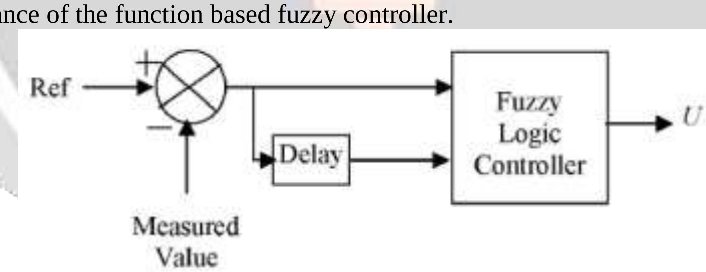

Fig.3:- Generalized block diagram of fuzzy logic controller [13].

An adaptive control design is proposed [14] to improve dynamic performances of voltage source converter high voltage direct current (VSC-HVDC) systems. The adaptive controller design for nonlinear characteristics of VSC-HVDC systems, which is based on back-stepping method, considers parameters uncertainties. For an original high-order system, the final control laws can be derived step by step through suitable Lyapunov functions. Thus, the design process is not complex. The effectiveness of the proposed adaptive controllers is demonstrated through digital simulation studies on a VSC-HVDC power system, using the PSCAD/EMTDC software package.

The controller's designs are based on the Sliding Mode Control (SMC) and Lyapunov's control methodologies [15] to deal with the nonlinearities introduced by requirements to power flow and line voltage. First, the steady state mathematical model of the HVDC Light system is developed and the decoupled relationship between the controlling variables is investigated. Then, the SMC and Lyapunov control techniques are resorted to govern the DC link voltage and to control the active and reactive powers. The main feature of this hypothesis is the robustness with respect to parameters' variations. Saturation, sigmoid and hyperbolic functions are used to avoid the issue of "chattering" caused by imperfect switching in the SMC. Based on Lyapunov method, the controller guaranteeing convergence of the state trajectory is developed.

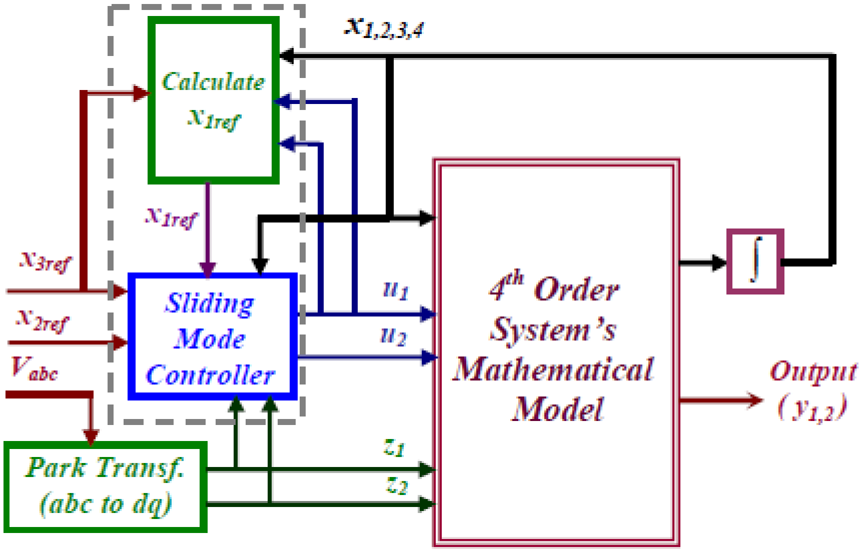

Fig.4:- VSC-HVDC with Sliding Mode Control (SMC).

A robust nonlinear controller for VSC-HVDC transmission link using input–output linearization and sliding mode-control strategy [16] was presented. The feedback linearization is used to cancel nonlinearities and the sliding mode control offers invariant stability to modeling uncertainties due to converter parameter changes, changes in system frequency, and exogenous inputs. Comprehensive computer simulations are carried out to verify the proposed control scheme under several system disturbances, such as changes in short-circuit ratio, converter parametric changes, and faults on the converter and inverter buses.

Author presents a solution for reducing the frequency oscillations in multi-area interconnected power system by means of using an VSC-HVDC interconnection transmission line. The upcoming power-electronics based HVDC transmission system offers new features that can be advantageous for improving the frequency control and thus for enhancing the stability in transmission networks. The first one is be devoted to introduce the basic elements of HVDC links and the second part will be focused on the effects of the HVDC links in the frequency control of interconnected power systems. In order to show the positive effects of HVDC links under random load disturbance, a model with parallel AC-DC interconnected power system, including a new power modulation controller of bi-directional VSC-HVDC link, is proposed and simulated.

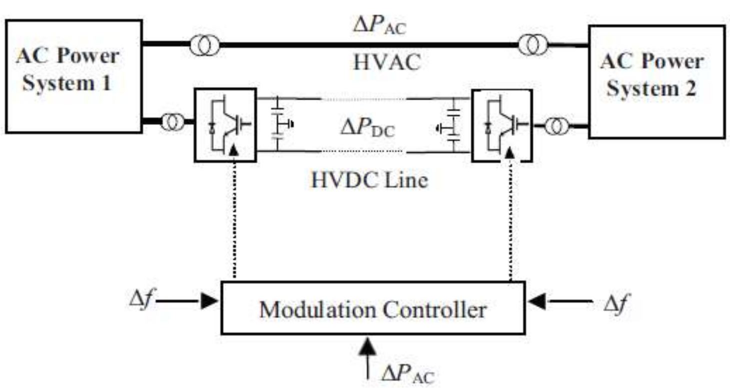

Fig.5:- The configuration of the power system with HVDC link.

A model suitable for small-signal stability analysis and control design of multi-terminal dc networks is presented. A generic test network that combines conventional synchronous and offshore wind generation connected to shore via a dc network is used to illustrate the design of enhanced voltage source converter (VSC) controllers. The impact of VSC control parameters on network stability was analyzed and the overall network dynamic performance assessed in the event of small and large perturbations.

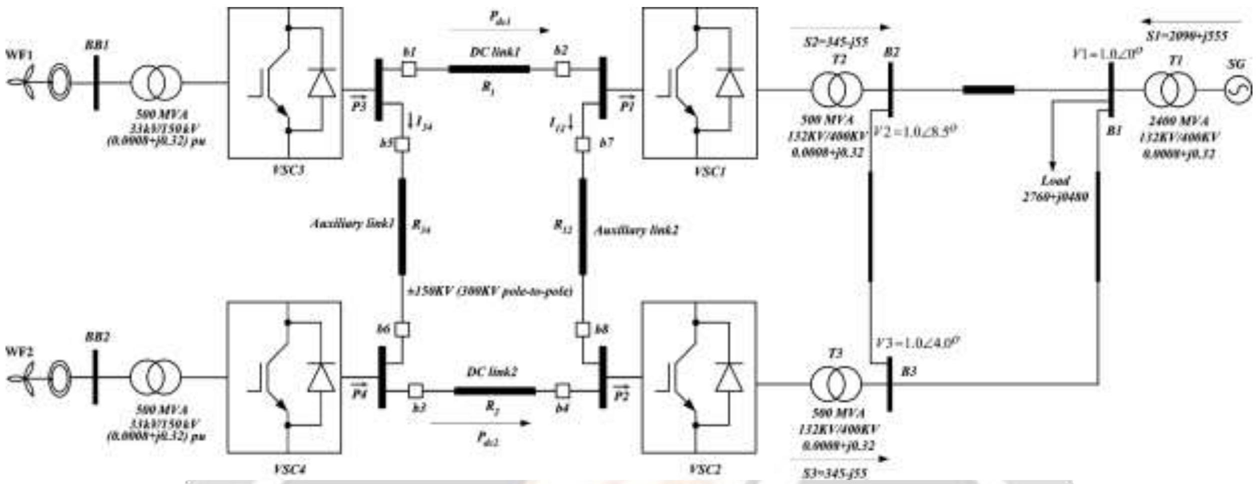

Fig.6:- Test system [18].

New breed of high-voltage dc (HVDC) transmission systems based on a hybrid multilevel voltage source converter (VSC) with ac-side cascaded H-bridge cells [19] was presented. The proposed HVDC system offers the operational flexibility of VSC based systems in terms of active and reactive power control, black start capability, in addition to improved ac fault ride-through capability and the unique feature of current-limiting capability during dc side faults. Additionally, it offers features such as smaller footprint and a larger active and reactive power capability curve than existing VSC-based HVDC systems, including those using modular multilevel converters. To illustrate the feasibility of the proposed HVDC system, this paper assesses its dynamic performance during steady-state and network alterations, including its response to ac and dc side faults.

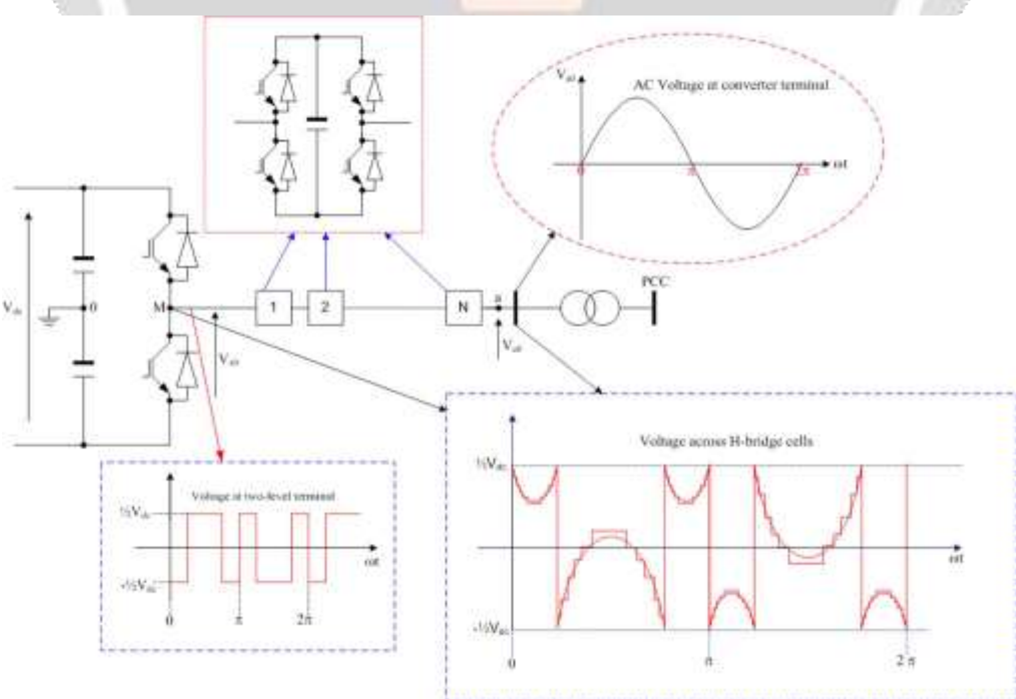

Fig.7:- Hybrid voltage multilevel converter with ac side cascaded H-bridge cells.

The control strategy [20] is based on a linear and bilinear state space deviation models. The structure of the control method is designed in order to minimize the number of the control loops (inner and outer control loops) in the classical strategy to one control loop for each output. These control loops are active power or DC voltage for the first output, and the reactive power for the other output. Simulations for VSC-HVDC transmission system model show the validity of the derived models and the effectiveness of the control strategies.

Table 1:- Different technology for VSC-HVDC system design.

Sr. No.	Name of Author & Year	Title of paper	Methodology	Claim by Author
1.	Si-Ye Ruan, Guo-Jie Li, Xiao-Hong Jiao, Yuan-Zhang Sun, T.T. Lie (2006)	Adaptive control design for VSC-HVDC systems based on backstepping method	The adaptive controller design for nonlinear characteristics of VSC-HVDC systems, which is based on backstepping method, considers parameters uncertainties. For an original high-order system, the final control laws can be derived step by step through suitable Lyapunov functions.	The design process is simple and clear because control laws can be derived step by step based on backstepping method. The proposed adaptive control contributes significantly to improved dynamic behaviors for VSC-HVDC systems. Thus, the adaptive control design is effective for VSC-HVDC systems containing parameters uncertainties.
2.	A. K. Moharana, Ms. K. Panigrahi, B. K. Panigrahi, and P. K. Dash (2006)	VSC Based HVDC System for Passive Network with Fuzzy Controller	The basic features of proposed system used in VSC based HVDC systems are: 1) only two rule base system is used.2) all controllers are not self correcting. At both stations error and change in error have been taken as input to the controller. Design of high pass filter with FFT analysis has also been proposed for a better dynamic performance of the function based fuzzy controller.	With proposed control strategy, quick response and dynamic stability have been achieved for any kind of changes and high level control accuracy is attained at different operating condition.
3.	H. S. Ramadan, H. Siguerdidjane and M. Petit (2008)	Robust Nonlinear Control Strategy for HVDC Light Transmission Systems Technology	The controller's design are based on the Sliding Mode Control (SMC) and Lyapunov's control methodologies to deal with the nonlinearities introduced by requirements to power flow and line voltage. First, the steady state mathematical model of the HVDC Light system is developed and the decoupled relationship between the controlling variables is investigated.	Although the controller based Lyapunov method is relatively simpler in implementation and its derivation is more complex, controllers based on SMC are preferable due to their better dynamic behaviors and more attractive robustness.

			Then, the SMC and Lyapunov control techniques are resorted to govern the DC link voltage and to control the active and reactive powers	
4.	Guanjun Ding, Guangfu Tang, Zhiyuan He, and Ming Ding (2008)	New Technologies of Voltage Source Converter (VSC) for HVDC Transmission System Based on VSC	The origin of modular multilevel VSC and its essential working mechanism are clarified in detail. Then, the effective protection measures of submodule and the technology of controlled submodule capacitor voltages balancing are discussed.	The output ac voltages can be adjusted in very fine increments. It minimizes the generated harmonics and in most cases completely eliminates the need for ac filters. Furthermore, the small and relatively shallow voltage steps cause very little radiant or conducted high-frequency interference.
5.	Akshaya Moharana, and P. K. Dash (2010)	Input-Output Linearization and Robust Sliding-Mode Controller for the VSC-HVDC Transmission Link	Presents a robust nonlinear controller for VSC-HVDC transmission link using input–output linearization and sliding mode-control strategy. The feedback linearization is used to cancel nonlinearities and the sliding mode control offers invariant stability to modeling uncertainties due to converter parameter changes, changes in system frequency, and exogenous inputs.	The proposed controller is found to be robust, producing significant damping and a reduction of overshoots for a variety of operating conditions that include short circuits at the converter buses, power reference changes for the rectifier and inverter, power reversal, low short-circuit ratio on the ac side, etc.
6.	Grain Philip Adam, Khaled H. Ahmed, Stephen J. Finney, Keith Bell, and Barry W. Williams (2013)	New Breed of Network Fault-Tolerant Voltage-Source-Converter HVDC Transmission System	Proposes a new breed of high-voltage dc (HVDC) transmission systems based on a hybrid multilevel voltage source converter (VSC) with ac-side cascaded H-bridge cells. The proposed HVDC system offers the operational flexibility of VSC based systems in terms of active and reactive power control, black start capability, in addition to improved ac fault ride-through capability and the unique feature of current-limiting capability during dc side faults. Additionally, it offers features such as smaller footprint and a larger active and	The main advantages of the proposed HVDC system are: potential small footprint and lower semiconductor losses compared to present HVDC systems, low filtering requirements on the ac sides and presents high-quality voltage to the converter transformer, does not compromise the advantages of VSC-HVDC systems such as four-quadrant operation; voltage

			reactive power capability curve than existing VSC-based HVDC systems, including those using modular multilevel converters.	support capability; and black-start capability, which is vital for connection of weak ac networks with no generation and wind farms, modular design and converter fault management (inclusion of redundant cells in each phase may allow the system to operate normally during failure of a few H-bridge cells; whence a cell bypass mechanism is required).
7.	Giovanni Beccuti, Georgios Papafotiou, and Lennart Harnefors (2014)	Multivariable Optimal Control of HVDC Transmission Links With Network Parameter Estimation for Weak Grids	The target is to develop a control method which, given the requested power and voltage values, yields an appropriate set of voltage references to be fed to the modulation scheme of the VSC. A parameter estimation scheme for the model employed in the model predictive control formulation is included.	the main advantage of which lies in the possibility to operate at high power levels with weak grid conditions. Although the control concept at the current stage of the work was not developed to the level of industrial implementation, it displays promising performance for very challenging operating settings for which traditional controllers fail to even yield stable operation.
8.	Mohamed Moez Belhaouane, Julian Freytes, Mohamed Ayari, Frderic Colas, Franois Gruson, Naceur Benhadj Braiek, and Xavier Guillaud (2016)	Optimal Control Design for Modular Multilevel Converters Operating on Multi-Terminal DC Grid	proposes an advanced control strategy for Modular Multilevel Converters (MMC) integrated in Multiterminal DC grid. In this present work, a three terminal MMC-MTDC system connecting onshore AC systems with an offshore wind farm is setup. Firstly, the voltage droop control associated to the conventional cascaded controllers for MMC stations is studied, the dynamic behavior of the DC voltage is analyzed and some drawbacks are	The proposed control method allows to reduce the oscillations and improves the DC bus voltage dynamics even for a lower droop parameters designed on static considerations. The advanced controllers associated to the classic droop control method improves MMC MTDC system stability and provides disturbance

			outlined. In order to improve the dynamic behavior of the controlled DC bus voltage and the stability of MTDC system, an optimal multivariable control strategy of each MMC converter is proposed and integrated in a voltage droop controller strategy.	rejection.
9.	Mohamed Moez Belhaouane, Mohamed Ayari, Naceur Benhadj Braiek and Xavier Guillaud (2016)	Nonlinear Modeling and Control of a VSC-HVDC Transmission Systems	Presents a new modeling and control strategy of VSC-HVDC transmission system in order to improve system damping oscillations, and enhancing transient and voltage stability. This control strategy is based on a linear and bilinear state space deviation models. The structure of the control method is designed in order to minimize the number of the control loops (inner and outer control loops) in the classical strategy to one control loop for each output. These control loops are active power or DC voltage for the first output, and the reactive power for the other output.	The reference inputs of active and reactive power and DC voltage can be tracked quickly using the feedback control strategy, and the active and reactive power of the VSC-HVDC system can be controlled independently.

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